NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3423

METHOD OF CONTROLLING STIFFNESS PROPERTIES OF A SOLID-CONSTRUCTION MODEL WING

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SUMMARY

A simple method is presented for controlling the bending and torsional stiffnesses of a solid-construction model wing. The method consists of weakening the wing by drilling holes through the wing normal to the chord plane. Aerodynamic continuity is maintained by filling the holes with a relatively soft material. The important parameters controlling the stiffnesses are the amount of material removed by drilling, the ratio of hole diameter to wing thickness, and the plan-form pattern of the holes. Data are given which may be used for predicting the stiffness of a model wing weakened in this manner.

INTRODUCTION

Many theoretical and experimental investigations of aeroelastic effects are being undertaken. It is readily apparent that, in the experimental investigations, control of the magnitude and distribution of the stiffness is very important. One method of controlling the stiffness of a model wing is to use a built-up construction, the interior members furnishing most of the stiffness and an outer covering furnishing the exterior form desired but contributing little to the overall stiffness. This method is difficult to use with small models having thin wing sections. A completely solid construction leads to difficulties in the selection of a suitable material because continuously varying physical properties are not readily available. Another approach to the model-design problem is to use a solid construction with a material that is too stiff and obtain the overall stiffness desired by local weakening (grooves, slots, holes, a porous basic material, etc.).

A short investigation was made to determine the important parameters and the effect of variations in these parameters for one method of weakening a solid-construction model wing by drilling holes through the wing normal to the chord plane. The specific purpose of the investigation was to obtain information for use in designing wings for flutter research for the Langley transonic blow-down tunnel; however, the data obtained may be of use to others engaged in aeroelastic-model investigations. Most of this investigation consisted of measurements of stiffnesses in bending and torsion obtained on weakened rectangular plates that resembled wings. Measurements of the frequencies of the lower natural modes were also made. Inasmuch as a wing with holes would be unsuitable aerodynamically, the effect of filling these holes with soft material in order to overcome this difficulty was investigated. The data obtained from the plates were used in weakening a model wing and the predicted and measured results are given.

SYMBOLS

EI	bending stiffness, lb-in.^{2}
GJ	torsional stiffness, lb-in.^{2}
f_h	natural bending frequency, cps
f_α	natural torsional frequency, cps

TEST SPECIMENS

The geometrical characteristics of the plates involved in this investigation are completely described by the plate thickness ratio, the ratio of hole diameter to plate thickness, the amount of material removed, and the plan-form pattern of the holes. The plates used to investigate the effects of the first three parameters had a square pattern; that is, the centers of the holes were located at corners of squares, the sides of which were parallel to the edges of the plate. A few other patterns with the same ratio of hole diameter to plate thickness and the same plate thickness ratio were tried. The basic plate size (a drilled area 2 inches wide, $\frac{1}{8}$ inch thick, and approximately $6\frac{1}{2}$ inches long) was used for convenience and its winglike proportions (panel aspect ratio of 3 and thickness ratio of 6.25 percent). The plates were made of aluminum alloy. In order to determine the effect of plate thickness ratio, a few plates with other values of thickness ratio (3.40 percent and 9.36 percent) were tested.

For a given hole pattern, the primary parameter governing the structural characteristics of any drilled plate is the amount of material removed. This parameter has been expressed nondimensionally as the ratio of minimum cross-sectional area of remaining metal to the undrilled cross-sectional area. For convenience, this term has been designated as percent of solid cross section. Values of this parameter ranged from 12.5 percent to 100 percent in the test plates. The percent of solid area of plan form has been included in table I. Four values of the ratio of hole diameter to plate thickness were covered: 0.5, 1.0, 1.5, and 2.0. All these values were used for the square pattern, and the 1.5 ratio was used for the staggered pattern.

The characteristics of all the test specimens used in the investigation are given in table I. Figure 1(a) shows some of the plates that had a square pattern, and figure 1(b) shows the plates with staggered patterns.

PROCEDURE

Each plate was clamped like a cantilever and loaded independently in bending and torsion as shown in figure 2. The average bending stiffness EI and the average torsional stiffness GJ were calculated from the resulting load-deflection curves.

The natural frequencies of each plate were determined for the lowest bending and torsional modes. In many cases, the frequencies for the next higher modes were also measured. These frequencies were determined by vibrating the plate with an electromagnetic vibrator driven by an oscillator. Some ambiguity may be present in the interpretation of the frequencies given for the weakened plates because of the undrilled area of the plate at the tip.

RESULTS AND DISCUSSION

Holes Arranged in Square Patterns

An inspection of the data in figures 3 to 9 reveals that, as might be expected, the amount of material removed is the variable having the greatest effect on stiffness. The data in figures 3 and 5 also show that the relationship between stiffness and material removed is not linear. Within the range of this investigation, the ratio of hole diameter to plate thickness has a negligible effect on the bending stiffness (fig. 4); however, this ratio may have a large effect on the torsional stiffness (figs. 5 and 6). The plate thickness ratio had little or no effect on ratio of stiffnesses of drilled plates to that of a solid plate (fig. 7). (The actual test points are shown in figures 6 and 7 as circles.)

The ratio of bending stiffness to torsional stiffness is of much interest in aeroelastic studies, and these data are shown in figure 8. The ratio of hole diameter to plate thickness is seen to have a large effect on the ratio of stiffnesses. This ratio of stiffnesses is reflected in the ratio of measured natural frequencies for the lowest bending and torsional modes (fig. 9). Plate 3 had two sizes of holes. The four rows nearest the spanwise center line of the plate had a ratio of hole diameter to plate thickness of 1.0. The remaining four rows consisted of holes, the diameter of which was 1.5 times the plate thickness. The unequal hole sizes had no significant effect on the stiffness properties of this plate.

Inasmuch as a model wing with holes would be unsuitable aerodynamically, the effect of filling and fairing the holes with a relatively soft material was investigated with one plate. The holes of plate 8 were filled with soft synthetic rubber, and the plate was redesignated as plate 10. This material presumably has very low values of tension and shear stiffnesses as compared with those of aluminum alloy. Table I shows that the measured stiffnesses of plates 8 and 10 are the same within the accuracy of these tests. However, the density of this rubber is approximately half that of aluminum alloy. The natural frequencies of plate 10 are therefore considerably lower than those of plate 8 because of the mass of the rubber. Since the effect of the low-stiffness filler is to add mass only, its effect on the natural frequencies may be estimated.

Holes Arranged in Miscellaneous Patterns

All the plates with holes arranged in a square pattern had undrilled strips of metal parallel and perpendicular to the elastic axis of the plate. One other plate had a hole pattern (plate 12, see fig. 1(b)) resulting in similarly oriented solid metal strips, but the holes were arranged to form short spanwise slots. The results obtained from this plate were not significantly different from those obtained from the plates with square patterns. (See fig. 4 to 8.)

Plates 6, 7, and 9 (fig. 1(b)) were drilled in patterns that resulted in solid strips of metal at angles to the elastic axis other than 0° and 90°. Figures 3 to 9 show that the pattern (plate 9) having these solid strips at 45° to the elastic axis resulted in a plate which, for a given amount of metal removed, was relatively much stiffer in torsion than in bending as compared with the other plates. Plates 6 and 7 show a similar, although much smaller, effect because the hole patterns resulted in solid metal strips at an angle of 26.5° to the elastic axis. Inasmuch as the effect of hole pattern was not thoroughly investigated, no definite design data can be given, but the possible large effect on stiffnesses and frequencies of hole pattern is shown.

Consideration of Some Practical Applications

The data obtained from the plates were used to design an unswept, tapered, aluminum-alloy wing which would have a torsional stiffness equal to 20 percent of the undrilled stiffness. This condition limited the range of bending stiffness from 30 percent to 42 percent of the solid-stiffness value, depending on the hole diameter selected for a square pattern. If bending stiffnesses beyond this range were desired, an investigation of different hole patterns would be necessary. This wing is shown in figure 10 and has an aspect ratio of 4, a taper ratio of 0.6, a span of 16.0 inches, and an NACA 65A004 airfoil section. The ratio of hole diameter to wing thickness was held to approximately 1.0. Inasmuch as number-size drills were used, neither the percentage of metal removed nor the ratio of hole diameter to plate thickness could be maintained exactly at every spanwise station. Figures 11 and 12 show the measured stiffnesses of the solid and drilled wings as a function of spanwise station. In addition, these figures show a predicted curve for the drilled wing which was obtained from the measured data of the solid wing and the plate data of figures 3 and 5. It would seem, then, that the data obtained from the plates can be used with reasonable accuracy in the design of actual model wings.

Limited flutter experience indicates that a drilled wing panel is sometimes less durable than a solid wing panel. Presumably, the lack of durability in the drilled panel is due to the stress concentrations near each hole.

One additional difficulty has been encountered in drilling model wings which were constructed of a compressed plastic-impregnated wood. When model wings constructed of compressed plastic-impregnated wood were drilled, the wing surface splintered as the drill point emerged. This difficulty resulted in stiffnesses below those predicted on the basis of flat-plate data. No such trouble was noted with metal models.

It should be mentioned that the strain gages used to measure bending and torsional frequencies at flutter operated satisfactorily although the gages spanned the drilled holes.

CONCLUDING REMARKS

A method of controlling the bending and torsional stiffnesses of a solid-construction model wing was briefly investigated. The method consisted of weakening the wing by drilling holes through the wing normal to the chord plane. The important variable controlling the properties of the perforated wing was the amount of metal removed. The effect of the hole pattern may also be very large. The ratio of hole diameter to plate thickness has an appreciable effect on the torsional properties of the drilled wing but only a small effect on the bending properties. Plate thickness ratio had no significant effect on the results. The data obtained from flat plates can be used successfully in the design of an actual model wing.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 6, 1955.

TABLE I

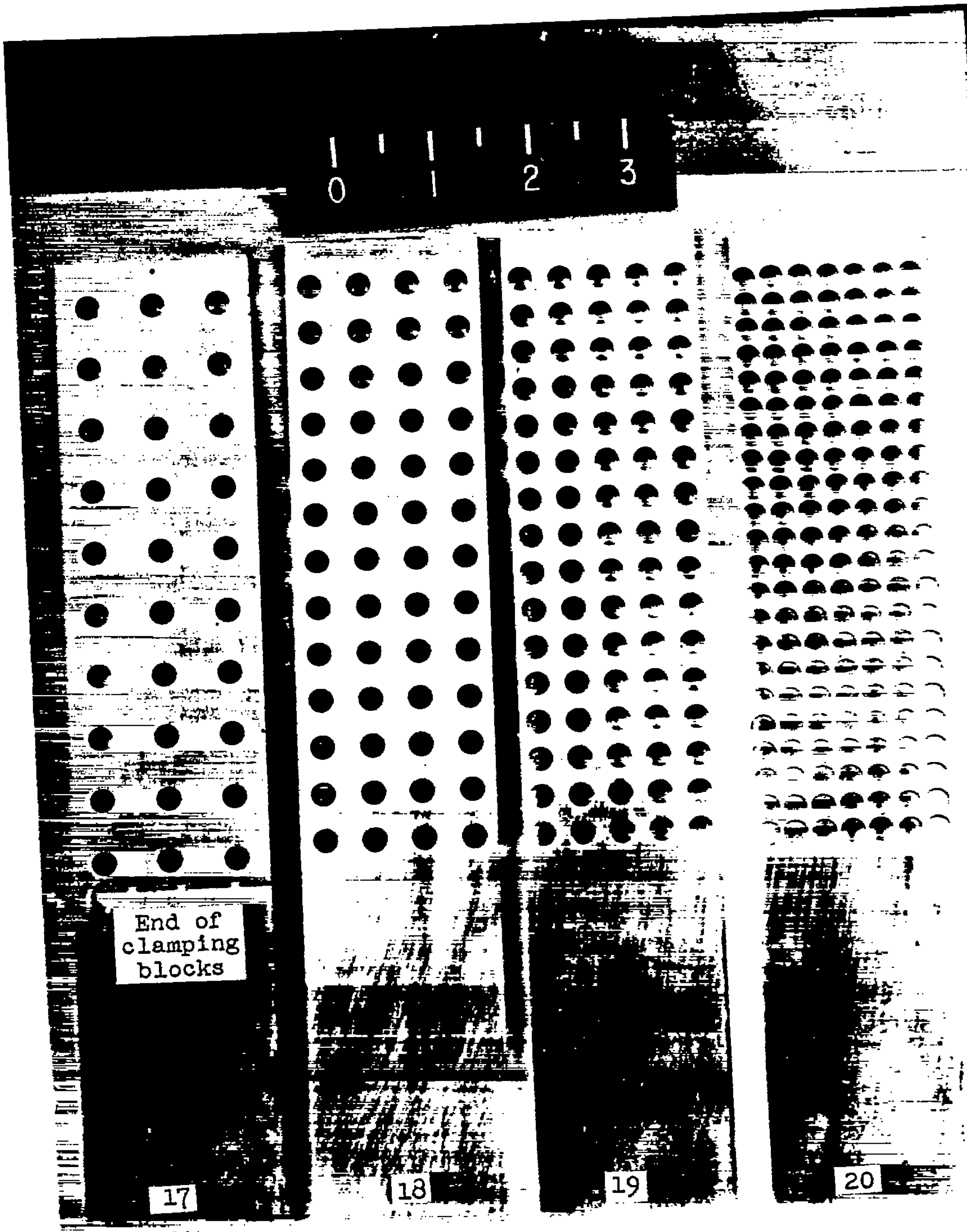
CHARACTERISTICS OF TEST SPECIMENS

	Plate												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Plate thickness, in.	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Plate thickness ratio, percent	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25
Hole diameter, in.	------	0.125	0.125 and 0.1875	0.1875	0.125	0.1875	0.1875	0.136	0.1875	0.136	0.0625	0.1875	0.125
Hole diameter/plate thickness	------	1.0	1.0 and 1.5	1.5	1.0	1.5	1.5	1.088	1.5	1.088	0.5	1.5	1.0
Hole spacing: chordwise, in.	------	0.250	0.250	0.250	0.167	0.125	0.158	0.167	0.158	0.167	0.083	0.250	0.333
spanwise, in.	------	0.250	0.250	0.250	0.167	0.250	0.316	0.167	0.158	0.167	0.083	0.1875 and 0.375	0.333
Number of holes in row: chordwise	------	8	8	8	12	8	6.0 and 6.45	12	6.0 and 6.45	12	24	8	6
spanwise	------	25	25	25	38	25	10	38	19 and 20	38	76	27	18
Solid cross section, percent	100	50	37.5	25	25	25	39.6	18.4	34.2	18.4	25	25	62.5
Solid plan-form area, percent	100	80.4	68.1	55.8	56.0	55.8	72.3	47.9	44.7	47.9	55.5	55.8	88.9
Hole pattern	None	Square	Square	Square	Square	Staggered	Staggered	Square	Staggered	Square	Square	Staggered	Square
Bending stiffness, EI, lb-in.^{2}	3,287	1,983	1,673	1,193	1,085	1,080	1,751	880	382	877	1,137	1,138	2,620
Torsional stiffness, GJ, lb-in.^{2}	4,920	3,070	2,232	1,283	996	1,600	2,800	610	1,397	623	752	1,200	3,900
Stiffness ratio, EI/GJ	0.668	0.646	0.750	0.930	1.089	0.675	0.618	1.443	0.273	1.443	1.512	0.948	0.672
Solid bending stiffness, percent	100	60.3	50.9	36.3	33.0	32.8	52.7	26.8	11.6	26.8	34.6	34.6	79.7
Solid torsional stiffness, percent	100	62.4	45.4	26.1	20.2	32.5	56.9	12.4	28.4	12.4	15.3	24.4	79.3
First bending mode, f_{h_1}, cps	82	72	68	68	66	61	69	60	44	48.5	60	60	80
Second bending mode, f_{h_2}, cps	530	482	468	440	430	405	455	400	304	330	422	380	525
Third bending mode, f_{h_3}, cps	------	------	------	1,180	1,140	1,120	1,200	1,120	850	930	1,180	1,090	1,420
First torsional mode, f_{α_1}, cps	590	475	505	397	347	430	505	298	485	222	306	380	565
Second torsional mode, f_{α_2}, cps	------	------	------	1,240	1,120	------	------	1,000	1,380	830	1,030	1,220	1,740
Ratio of natural frequencies, f_{h_1}/f_{α_1}	0.139	0.151	0.135	0.171	0.190	0.142	0.137	0.201	0.091	0.218	0.196	0.158	0.142

TABLE I - Concluded

CHARACTERISTICS OF TEST SPECIMENS

	Plate												
	14	15	16	17	18	19	20	21	22	23	24	25	26
Plate thickness, in.	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.068	0.1875	0.1875	0.065
Plate thickness ratio, percent	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25	3.40	9.37	9.37	3.25
Hole diameter, in.	0.125	0.125	0.250	0.250	0.250	0.250	0.250	0.0625	0.0625	0.0625	0.1875	------	------
Hole diameter/plate thickness	1.0	1.0	2.0	2.0	2.0	2.0	2.0	0.5	0.5	1.088	1.0	------	------
Hole spacing: chordwise, in.	0.200	0.143	0.333	0.667	0.500	0.400	0.286	0.167	0.100	0.083	0.250	------	------
spanwise, in.	0.200	0.143	0.333	0.667	0.500	0.400	0.286	0.167	0.100	0.083	0.250	------	------
Number of holes in row: chordwise	10	14	6	3	4	5	7	12	20	24	8	------	------
spanwise	30	42	18	9	12	15	21	38	60	76	25	------	------
Solid cross section, percent	37.5	12.5	25	62.5	50	37.5	12.5	62.5	37.5	25.0	25.0	100	100
Solid plan-form area, percent	69.3	40.0	55.7	89.0	80.4	69.3	40.0	89.0	69.3	55.5	55.8	100	100
Hole pattern	Square	Square	Square	Square	Square	Square	Square	Square	Square	Square	Square	None	None
Bending stiffness, EI, $lb\text{-}in.^2$	1,565	621	1,154	2,500	2,205	1,742	696	2,540	1,548	174	3,920	11,100	540
Torsional stiffness, GJ, $lb\text{-}in.^2$	1,960	222	1,530	4,220	3,620	2,610	411	3,800	1,667	146	3,390	16,850	830
Stiffness ratio, EI/GJ	0.798	2.797	0.754	0.592	0.609	0.667	1.693	0.668	0.929	1.184	1.156	0.659	0.651
Solid bending stiffness, percent	47.6	18.9	35.1	76.0	67.1	53.0	21.2	77.3	47.1	32.1	35.3	100	100
Solid torsional stiffness, percent	39.8	4.51	31.1	85.8	73.6	53.0	8.35	77.2	33.9	17.6	20.1	100	100
First bending mode, f_{h_1}, cps	70	54.5	70	78	77	72	56	80	70	34.5	94.5	126	44
Second bending mode, f_{h_2}, cps	448	368	425	505	505	460	375	515	460	241	640	790	278
Third bending mode, f_{h_3}, cps	1,260	1,050	1,190	1,380	1,360	1,270	1,080	1,420	1,216	------	------	2,200	820
First torsional mode, f_{α_1}, cps	452	195	432	560	550	507	261	550	430	174	525	850	309
Second torsional mode, f_{α_2}, cps	1,420	750	1,560	1,720	1,690	1,560	890	1,700	1,330	------	1,670	2,680	960
Ratio of natural frequencies, f_{h_1}/f_{α_1}	0.155	0.279	0.162	0.139	0.140	0.142	0.214	0.145	0.163	0.198	0.180	0.148	0.142



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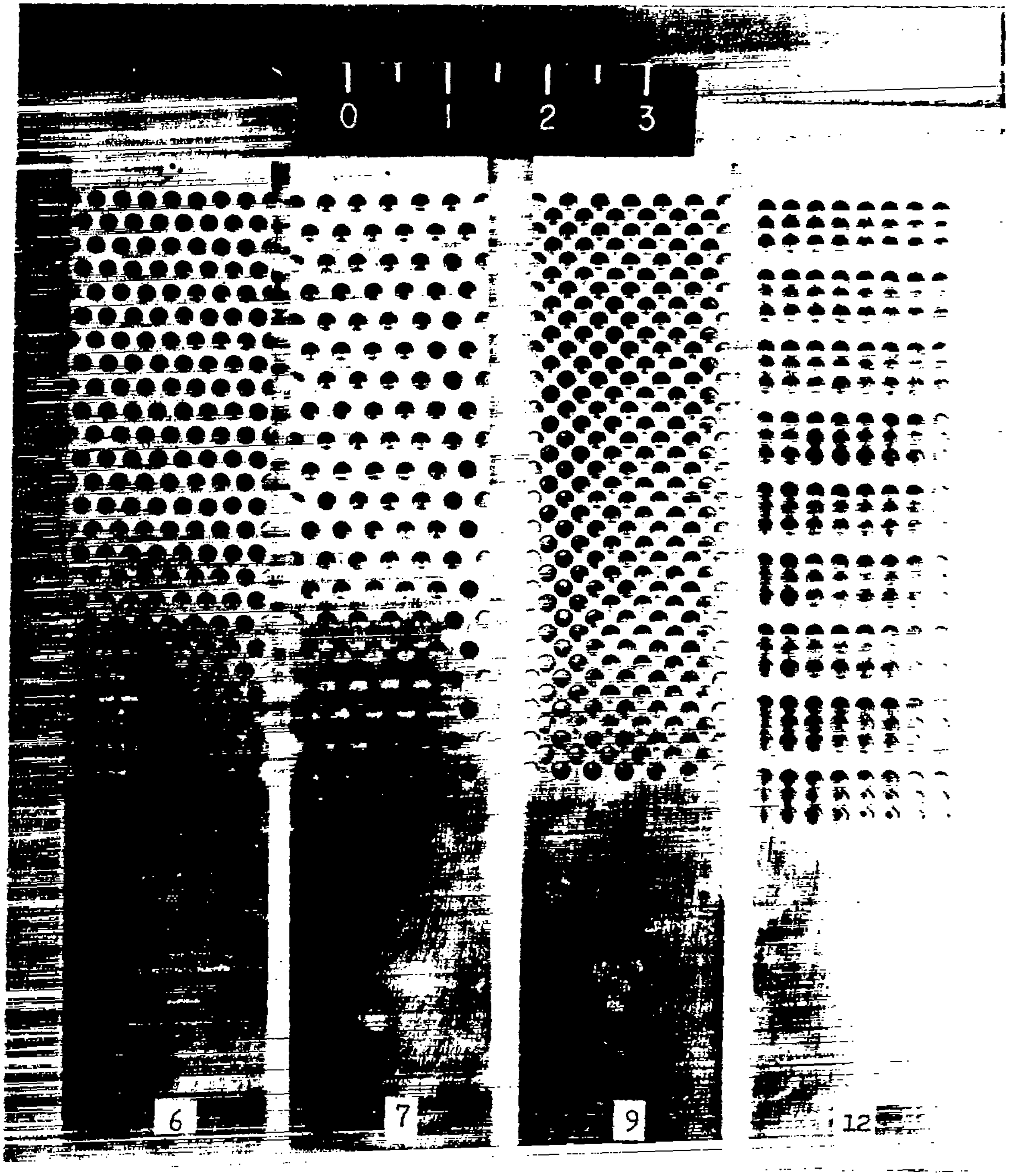
(a) Specimens with square patterns.

Figure 1.- Examples of test specimens.



(b) Specimens with staggered patterns. L-83457.1

Figure 1.- Concluded.

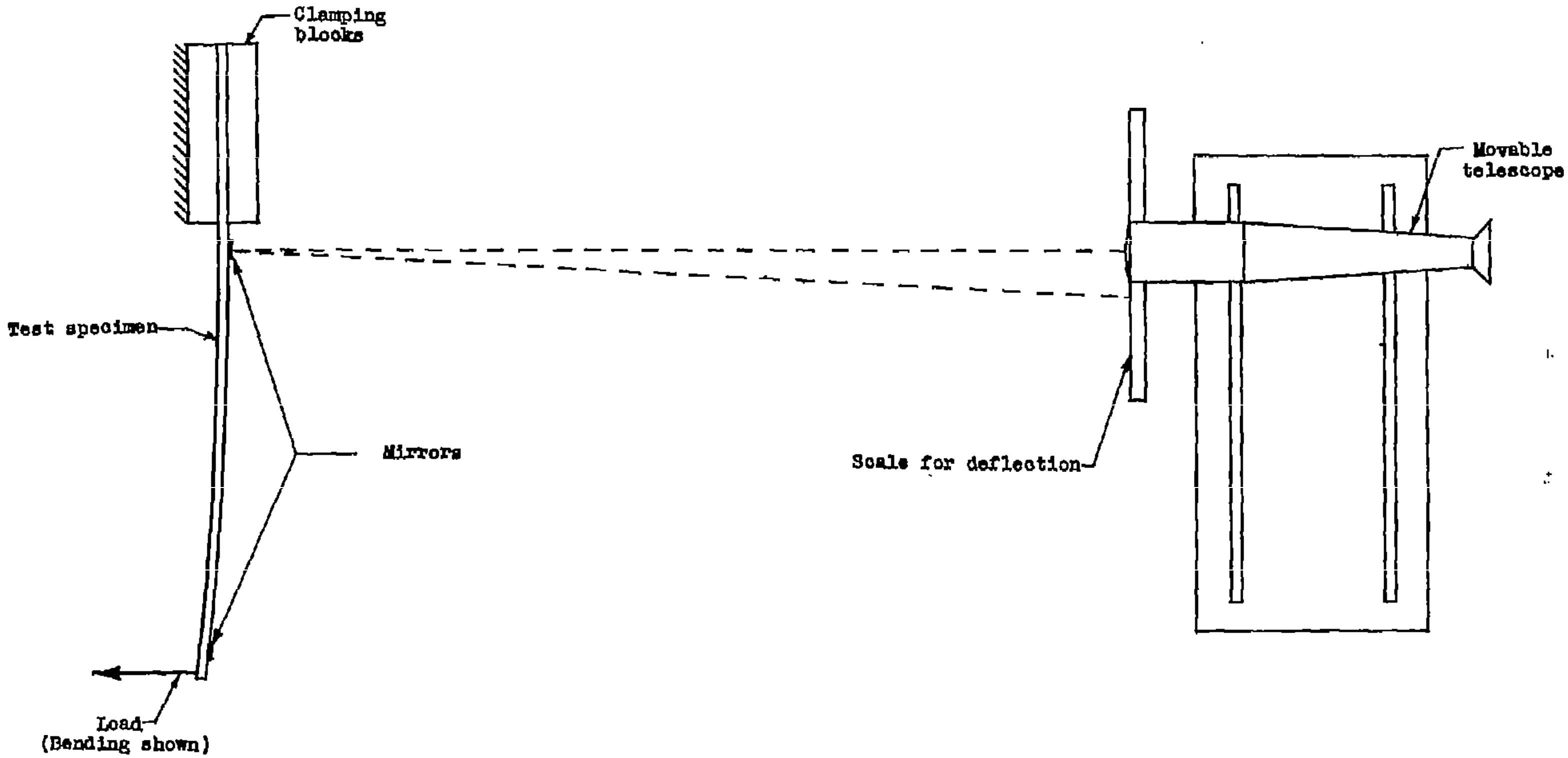


Figure 2.- Schematic diagram of stiffness-measuring setup.

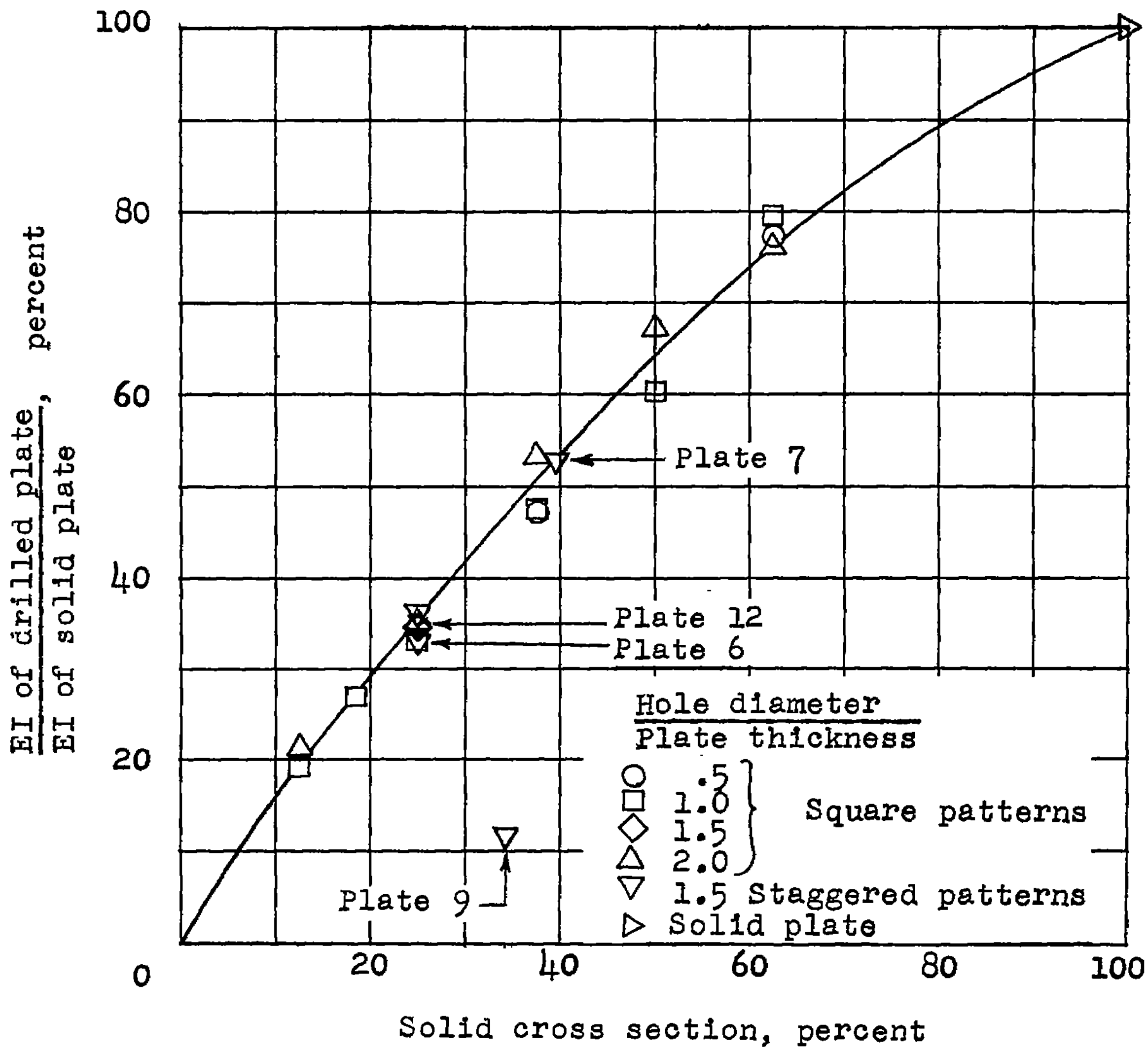


Figure 3.- Variation of bending stiffness with amount of material remaining.

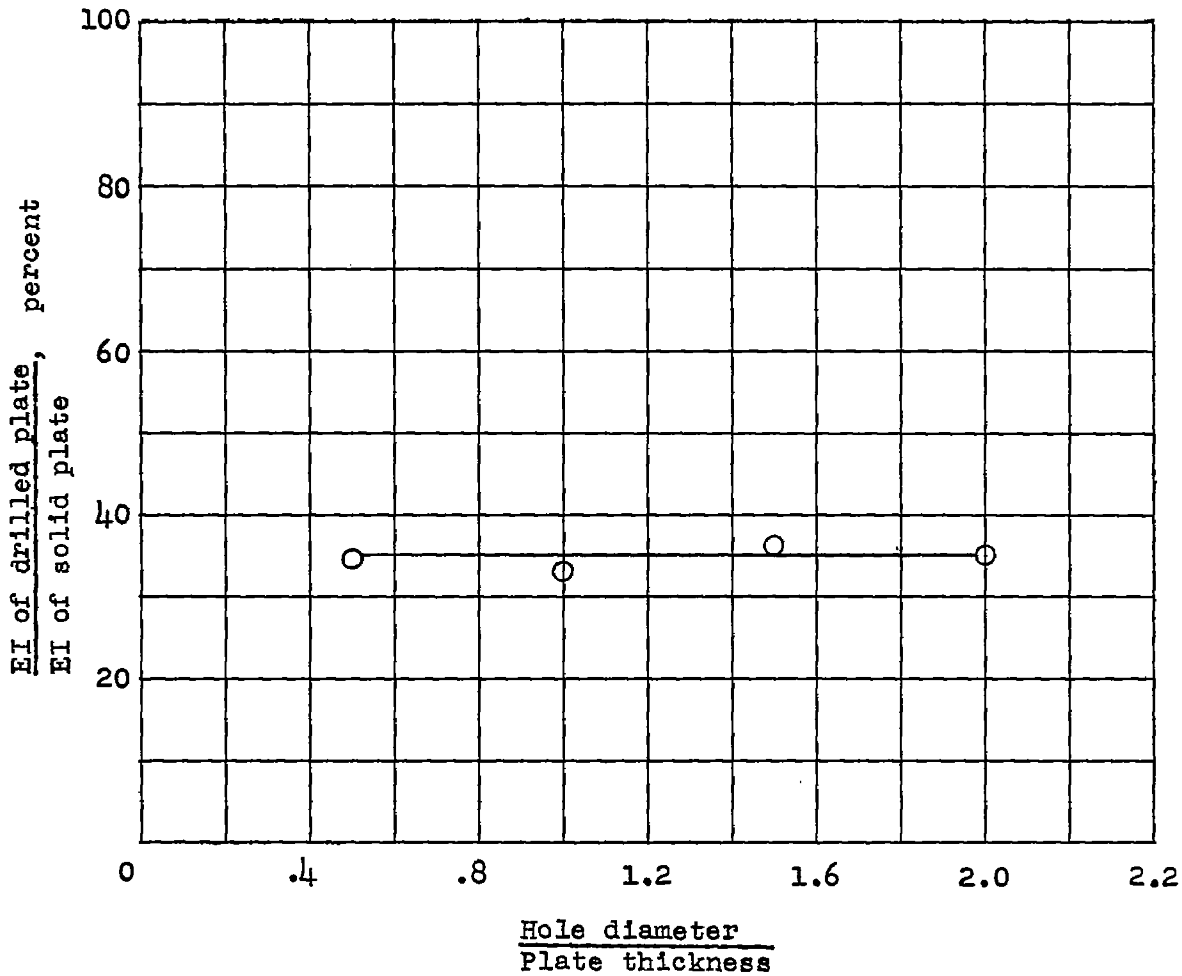


Figure 4.- Effect of ratio of hole diameter to plate thickness on bending stiffness. 25 percent solid cross section.

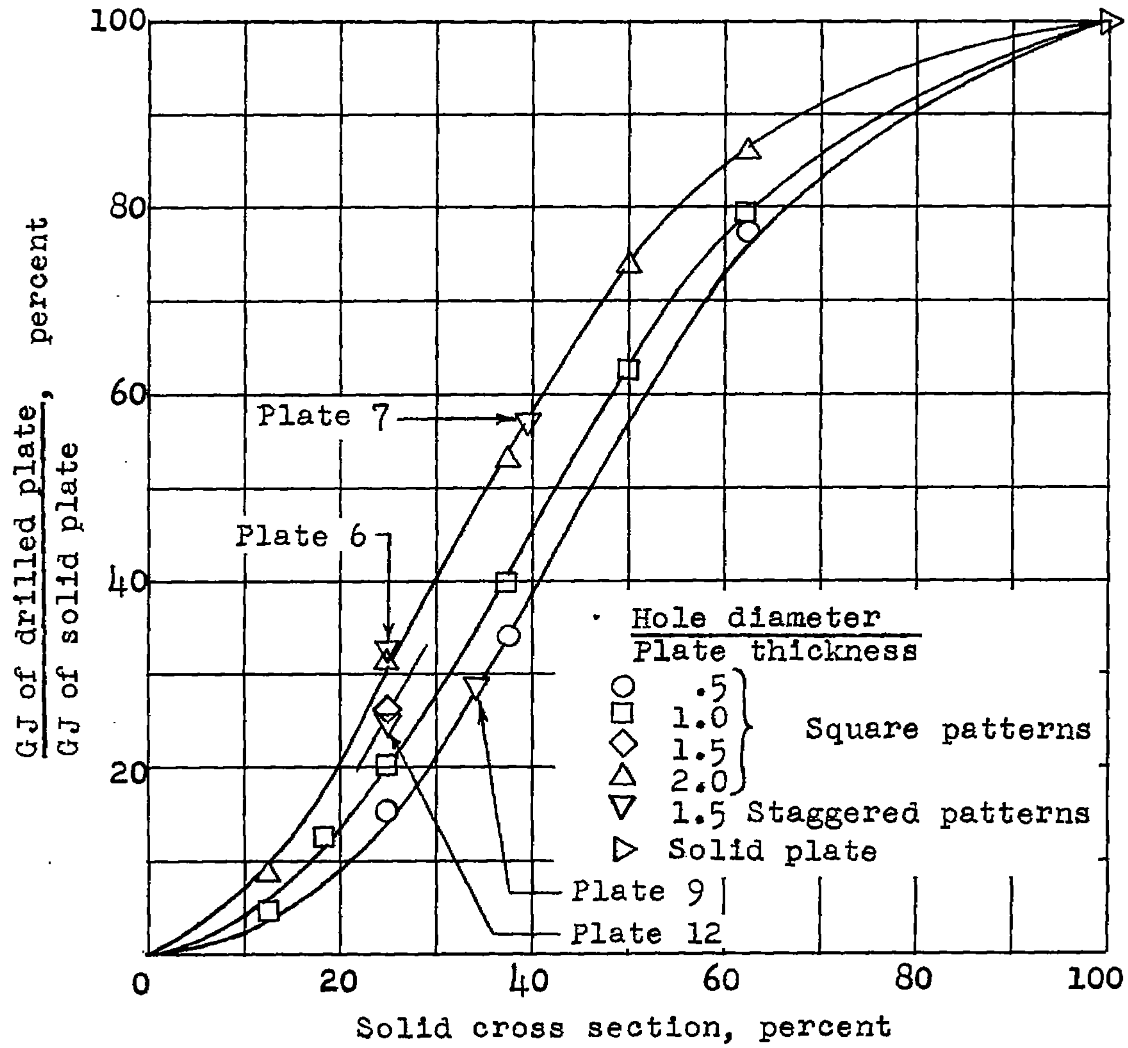


Figure 5.- Variation of torsional stiffness with amount of material remaining.

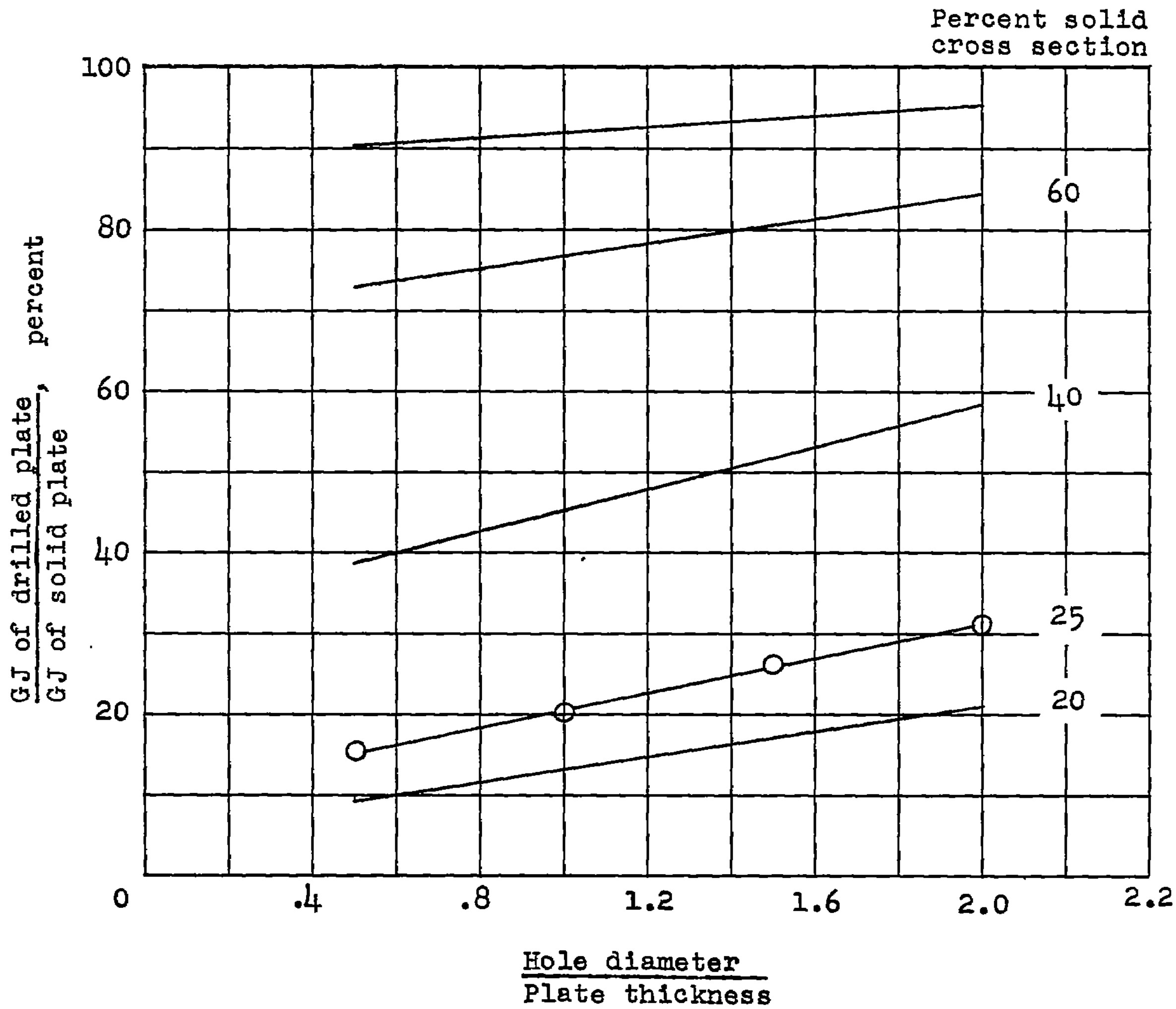
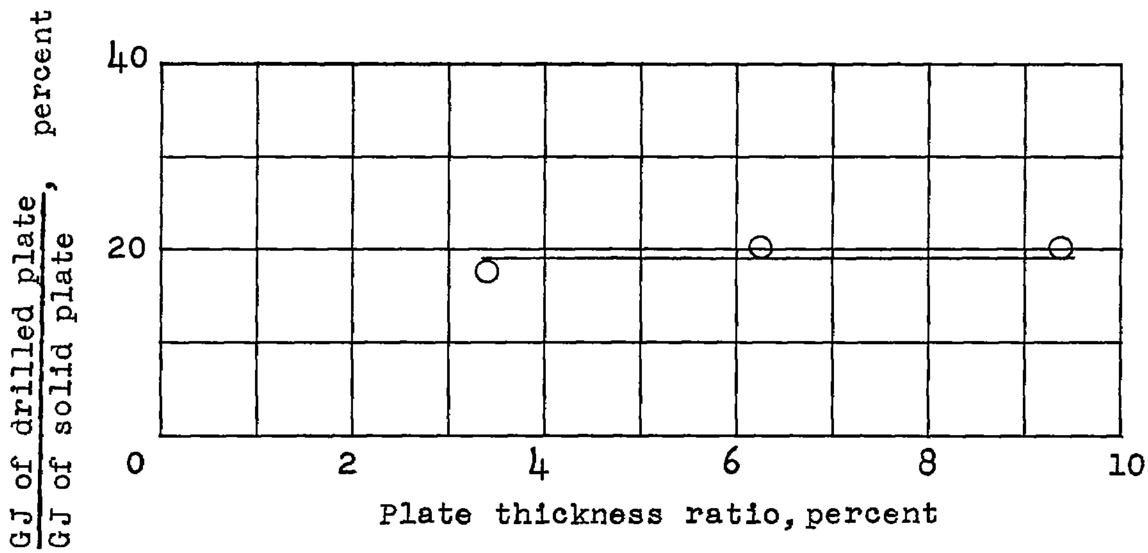
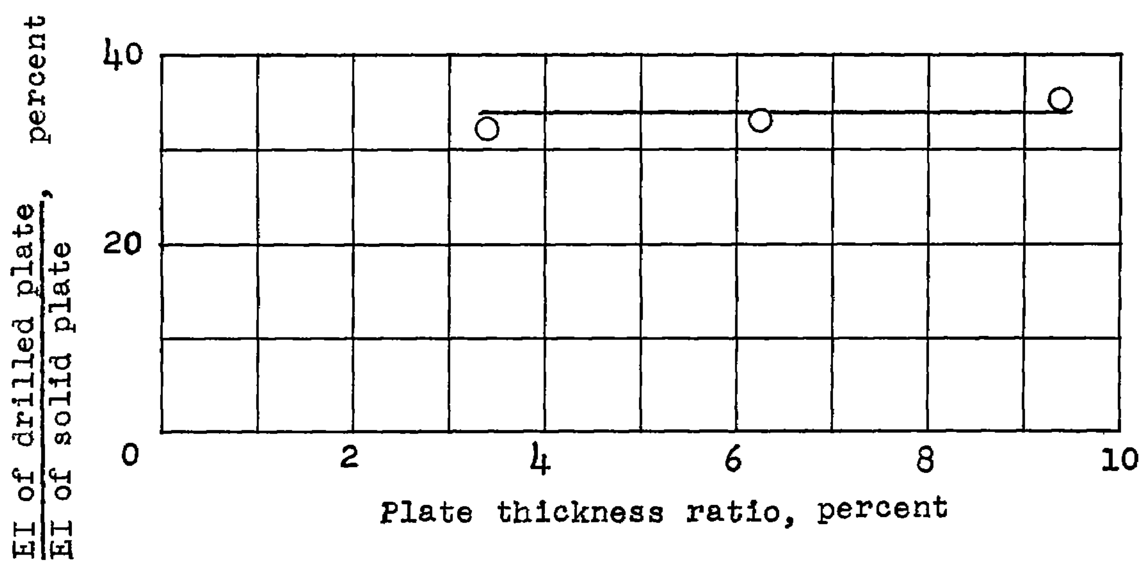


Figure 6.- Effect of ratio of hole diameter to plate thickness on torsional stiffness.



(a) Torsional stiffness.



(b) Bending stiffness.

Figure 7.- Effect of plate thickness ratio on torsional and bending stiffnesses.

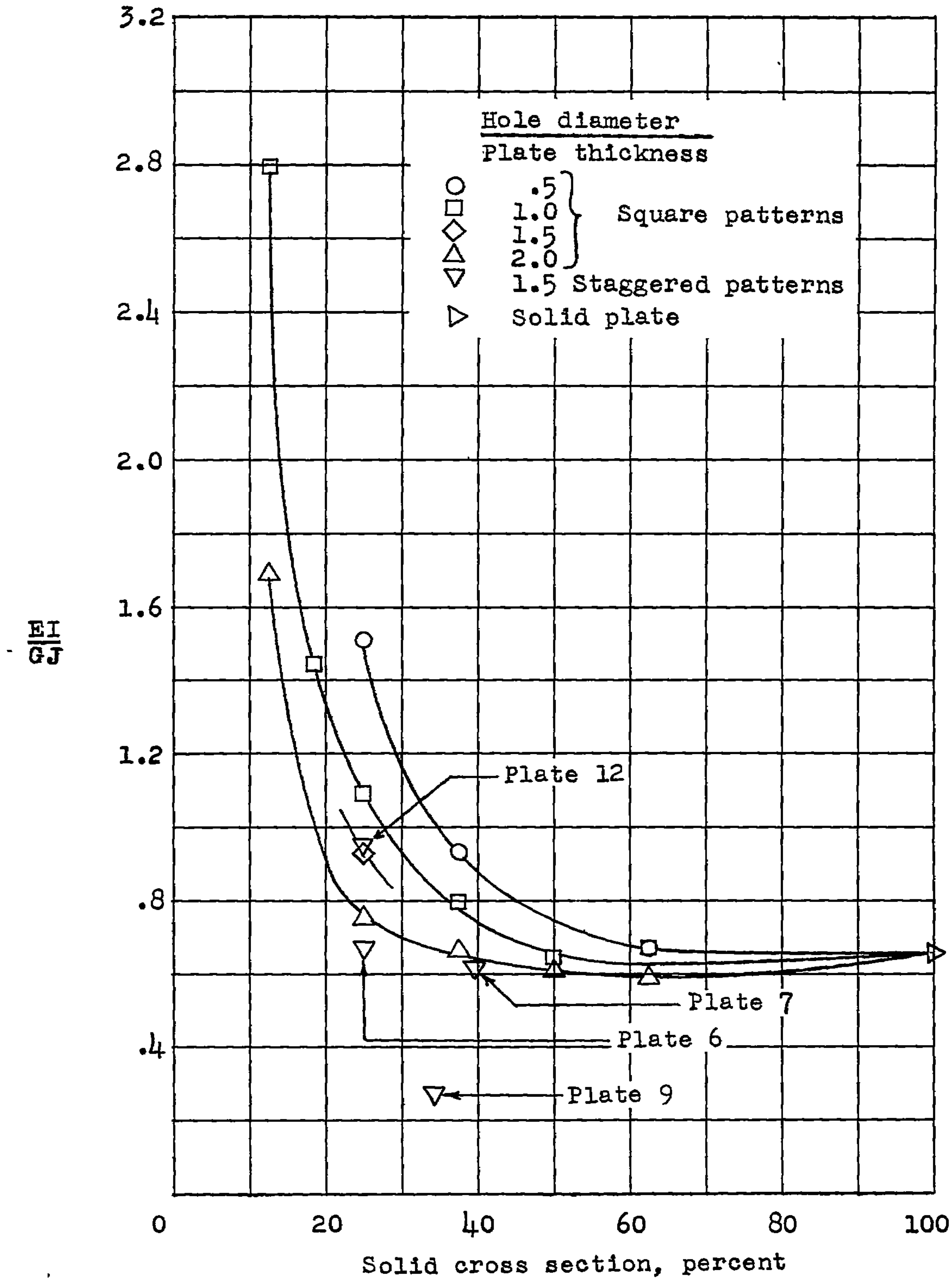


Figure 8.- Variation of ratio of bending to torsional stiffness with amount of material remaining.

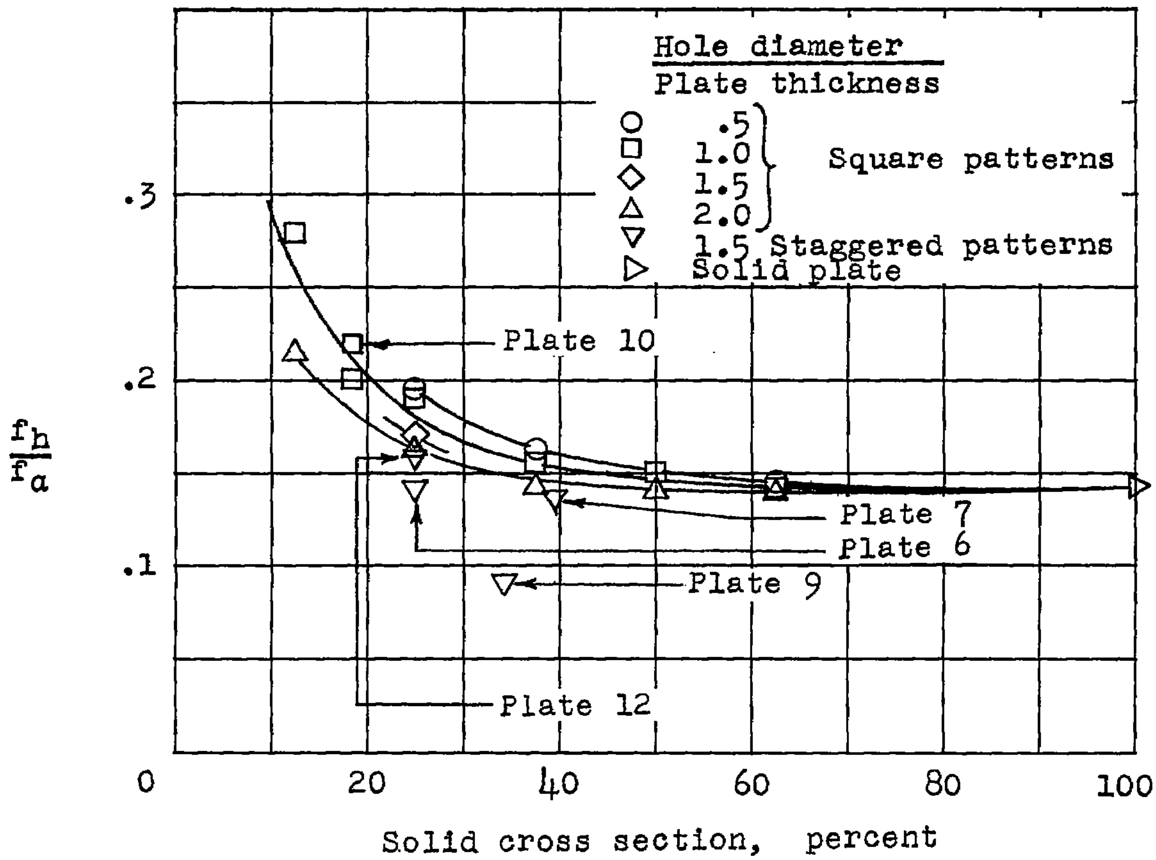


Figure 9.- Variation of frequency ratio with amount of material remaining.

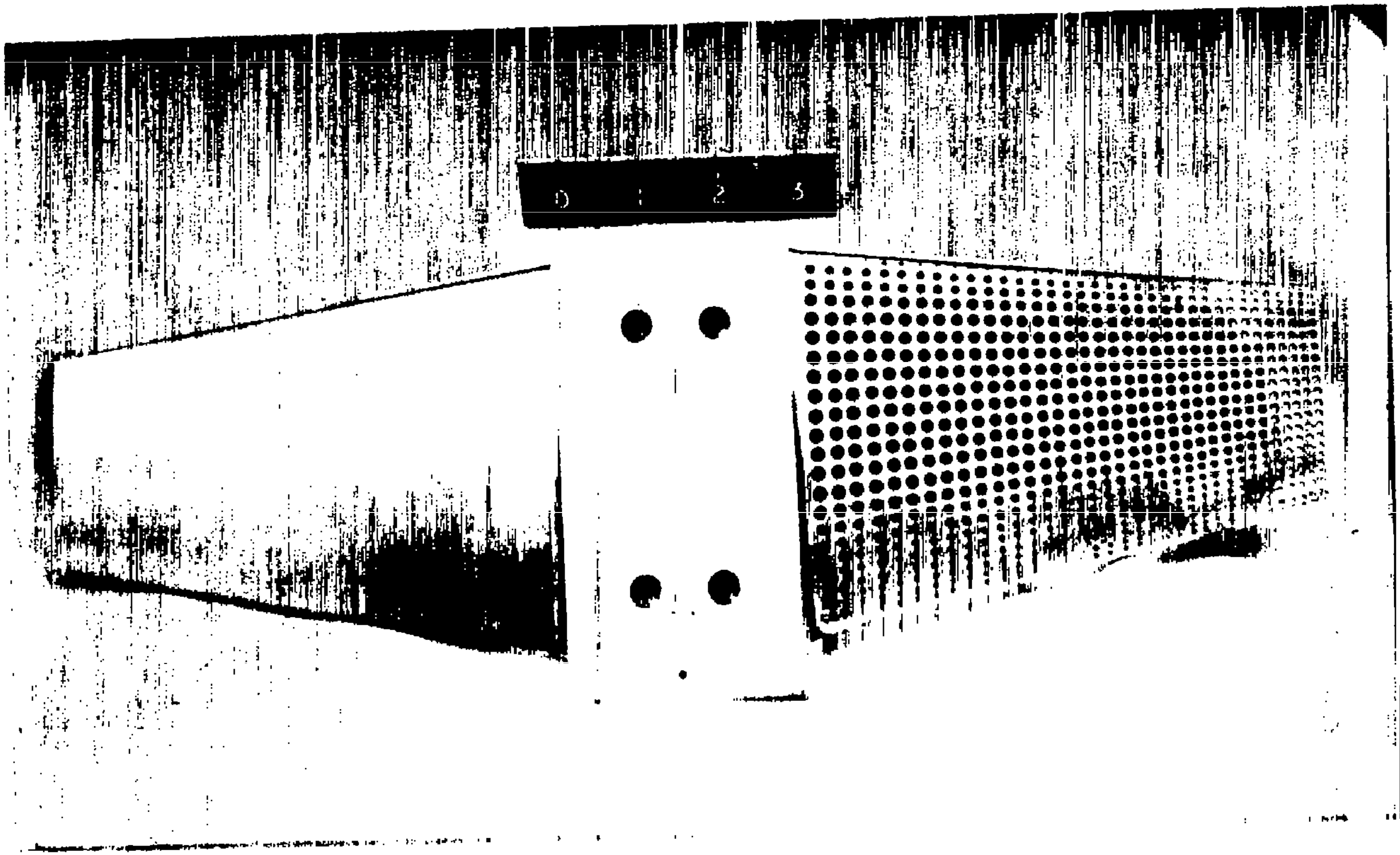


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Figure 10.- Tapered-wing model showing one panel drilled.

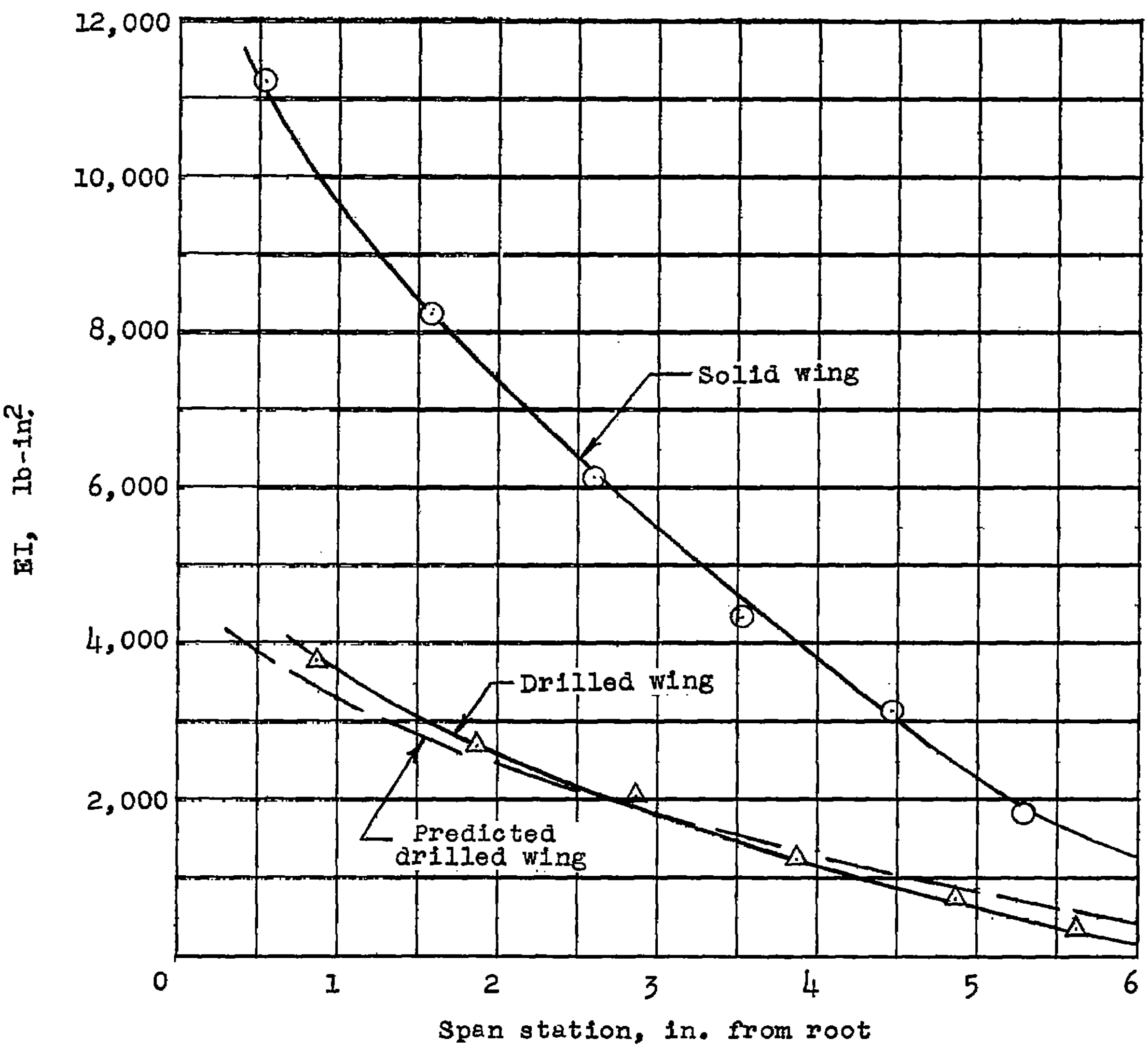

Figure 11.- Bending stiffnesses of solid and drilled wings.

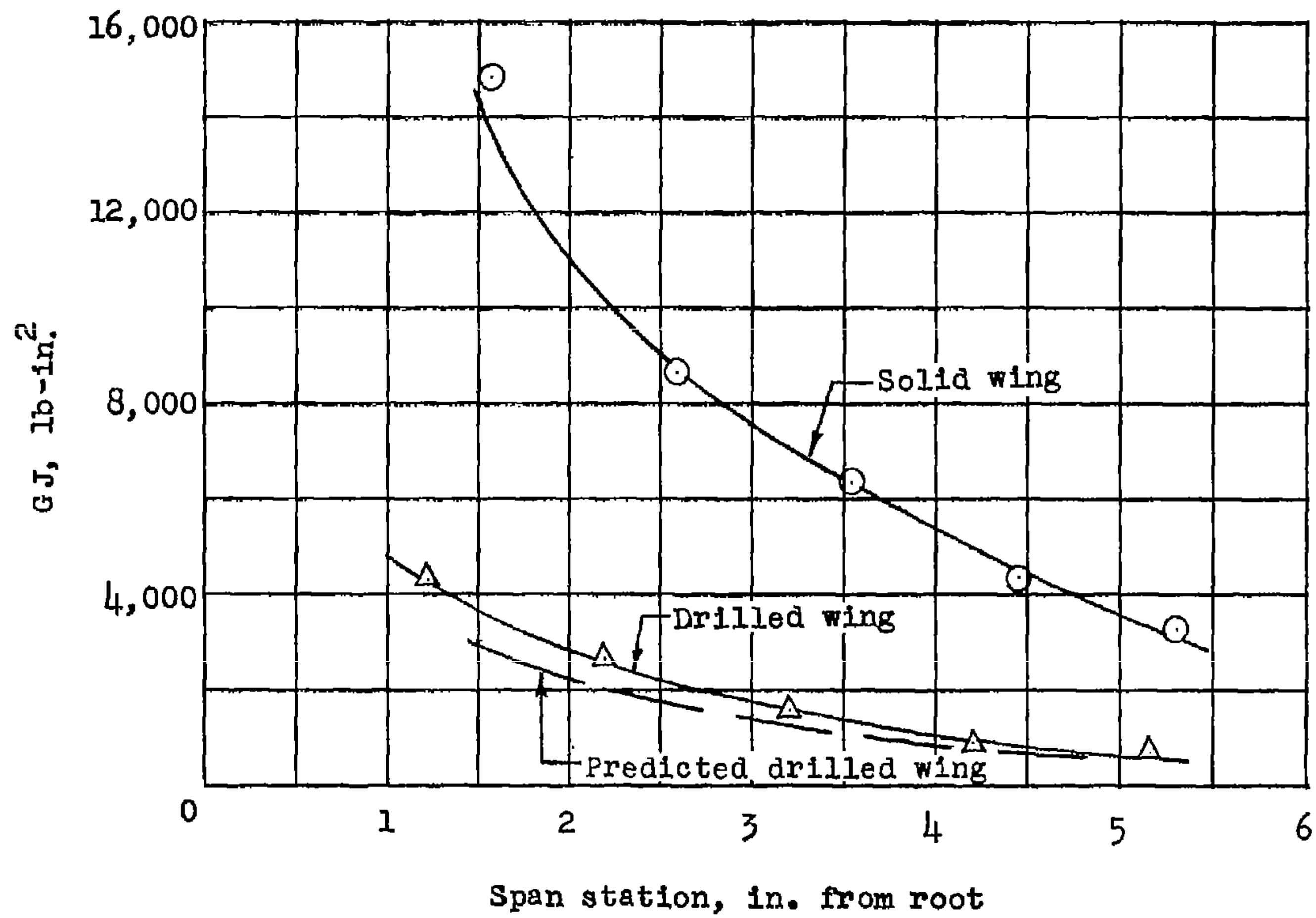

Figure 12.- Torsional stiffnesses of solid and drilled wings.

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